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The role of kinematic mental simulation in creating false memories

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Abstract

Our investigation focuses on memory for scenes depicted in photos. According to the mental model theory, the observation of a static scene depicted in a photo which portrays an actor near to perform an action can trigger a kinematic mental simulation of that action unfolding in time. The deriving prediction is that such kinematic mental model supports the creation of a false memory of the actor performing an advanced phase of the action. We test this prediction in three experiments in which participants are presented with static scenes of actions, and after three days they perform a recognition task in which they assess recognition of old and novel static scenes depicting actions. The results confirm that false memories occur for actions that represent the unfolding over time of the static action initially observed. Our theoretical framework can accommodate also several previous findings in the literature on false memories.

Keywords: false memories, kinematic mental models, memory for actions

Introduction

Several studies in the literature highlight the role of suggestion in the formation of false memories. For example, false memories of self-performed actions can result from either imagining to perform an action (imagination-inflation effect, Garry, Manning, Loftus, & Sherman, 1996; Goff & Roediger, 1998) or observing another individual while performing the action (observation-inflation effect, Lindner, Echterhoff, Davidson, & Brand, 2010). Most recently, it has been found that also creating a mental image of another person performing an action (Lindner & Echterhoff, 2015) as well as listening to the sound of someone performing actions (Lindner & Henkel, 2015) can trigger false memories of self-performance.

Also self-produced actions or sequences of interrelated actions can yield to false memories. In a study by Henkel (2011) the participants performed a series of actions (phase 1), later on viewed a series of photos representing finished actions (phase 2), then performed a memory test (phase 3). The test detected false memories. For example, if the participants in phase 2 viewed a photo depicting a glass full of water and an empty bottle, in phase 3 they were likely to believe having performed in phase 1 an action that, although being necessary to complete the final scene represented in the photo, they did not actually perform (e.g., pouring out the water). Analogously, the participants in a study by Foster and Garry (2012), after a construction task in which they performed some steps of the task while other steps were performed by the experimenter (unseen by the participant), falsely remembered having completed the experimenter-performed steps.

False memories can arise also from observation of movies or still frames of sequences of actions, as well. Gerrie, Belcher and Garry (2006) found that when the participants in their experiment saw a movie of a woman making a sandwich, and some actions were missing in the movie, in a subsequent memory test they falsely remembered 17% of unseen elements from the event. It happens that seeing frames of sequences of actions depicting an effect but not a cause, can lead, in a recognition test, to mistake new cause scenes as old, i.e., to automatically draw backward inferences (Hannigan & Reinitz, 2001). Foster and Garry (2012) argue that these findings about the effects of seeing movies or sequences of actions can be explained by assuming that people use the relationship between items to internally generate the missing related information. However, the mental processes underlying the generation of the missing related information have been not investigated.

Stemming from this literature, the aim of the present investigation is threefold. First, we explore the possibility that false memories arise not only from the observation of series of still frames (i.e., Hannigan & Reinitz, 2001), but also from the observation of a single still frame portraying an action (i.e., a single photo). Second, we assessed whether false memories can be obtained for actions that represent a “logical” and temporal continuation of the action that is seen in the still frame (future rather than past), even when performed by another individual. Third, we shed light on the cognitive mechanism underlying the creation of this kind of false memories. The assumptions of the mental model theory (Johnson-Laird, 1983; 2006) easily predict the occurrence of false memories in response to still frames portraying actions, as tested in this study, and explain the results on false memories for actions reported above. These aims were assessed in three experiments.

Mental model theory, kinematic mental simulations and false memories

Mental model theory (Johnson-Laird, 1983; 2006) assumes that the deep comprehension of a state of affairs is tantamount to the construction of a mental model. A mental model is an iconic mental representation in which the elements and the relations among such elements stand, respectively, for the entities in the state of affairs perceived or described and for the relations among these entities. Differently from a mental image, which is also an iconic mental representation, a mental model represents a set of states of affairs rather than a single state of affairs. Mental models can be either static or kinematic. A kinematic model unfolds in time, and the sequence of situations that it represents corresponds to the temporal order of events in the world, real or imaginary (Johnson-Laird, 1983; Schaeken, Johnson-Laird, & d'Ydewalle, 1996); the kinematic simulation is akin to a mental "movie" (Hegarty, 1992; Johnson-Laird, 1983). However, a kinematic model is not a holistic and dynamic mental image. Evidence of the difference between a kinematic mental simulations and a mental image comes from studies in which the task of the participants was to infer the behavior of a mechanical system made of three pulleys connected by a rod, and one above the other (so that by pulling the rod the pulleys rotate in different directions), from a visual-spatial representation (a static diagram) of that mechanical system. Experimental evidence suggests that the task relies on a mental animation process involving the decomposition of the representation of the pulley system into smaller units corresponding to the machine components, and animating these components in a sequence corresponding to the causal sequence of events in the machine's operation (see, for a review, Hegarty, 2004). Hegarty (1992) found that people, when told that the rod is pulled from the higher hand, take more time to infer the motion of the bottom pulley, than the middle pulley and more time to infer the movement of the middle pulley than the top pulley. She reasoned that people infer the motion of the components piecemeal, beginning by imagining the moving rope being pulled, and working through the causal chain of events in the motion of the system. This evidence that mechanical reasoning involves sequentially propagating the effects of local interactions between components is inconsistent with the assumption that the mental simulation consists in the inspection of a holistic and dynamic mental image of the moving mechanism. If so, all the parts of the system would move together in the mental image and an inspection of such an image would allow fast responses about the movement of any part of the system. But it is not so. The mental simulation is based on a dynamic mental model, and not simply on a mental image.

Mental model theory also dissociates inferential processes obtained through mental simulation from reasoning based on descriptive and propositional knowledge (like scripts or schemas). Provided the existence of separate buffers in working memory specialized for maintaining visuospatial representations and verbal representations (Baddeley, 2002), studies demonstrated that visuospatial working memory load interferes more than verbal working memory load with tasks involving kinematic mental simulation such as mechanical reasoning, and similarly, mechanical reasoning interferes more with the visuospatial than the verbal memory loading task (Sims & Hegarty, 1997).

Within a mental model perspective, kinematic mental simulations are central in thinking and reasoning. Consistent with this, studies in the literature showed that individuals construct small-scale simulations of possible interactions among parts when trying to understand mechanisms (Hegarty, 2004) as well as physical scenes (Battaglia, Hamrick, & Tenenbaum, 2013), and they run kinematic mental simulations to deduce from algorithms and to abduce algorithms (Bucciarelli, Mackiewicz, Khemlani, & Johnson-Laird, 2016; Khemlani, Mackiewicz, Bucciarelli, & Johnson-Laird, 2013).

The predictions derived from the mental model theory’s assumptions have been widely tested in the formal reasoning domain, as well as in the domain of discourse comprehension; they are mainly concerned with the valid inferences resulting from models’ construction and manipulation. We know from the literature on mental models that individuals who built an articulated mental model from a discourse, compared to individuals who built a less articulated model, are more likely to draw correct, discourse-based inferences, and they are less likely to remember the surface form of that discourse (Cutica & Bucciarelli, 2008). In the present investigation we focus on the mental kinematic simulation that people make during the comprehension of a static situation depicted in a photo, rather than a discourse. The photo depicts an individual “near to perform” an action. Specifically, we investigate whether false memories can arise from such kinematic mental models constructed from the static action depicted in the photo (i.e., erroneously remembering of having seen the actor dynamically performing the action). We predict participants to remember having seen actions that were not presented, but that are part of the kinematic mental simulation stemming from the actions presented. Our argument is reinforced by neurocognitive studies on action observation. Several neurocognitive studies largely demonstrated that when people observe an action of other individuals, their motor system is automatically involved and activated (e.g., Buccino, Binkofski, Fadiga, Fogassi, Gallese et al., 2001). It has been argued that this motor recruitment allows the observer to immediately understand what other people are doing and to interpret another person’s action (Rizzolatti & Sinigaglia, 2010). Most relevant, the observer’s motor system is selectively recruited also when the participants observe a still actor that potentially could act on an object that falls within his reaching space (Cardellicchio, Sinigaglia, & Costantini, 2012). The authors of these studies suggest that observed actions are matched to actions in the observer motor repertoire thus automatically allowing predictions about what others are going to do next. Other studies detected a crucial role of the contextual information in action understanding, given that the knowledge about an object placed in the peripersonal space of another person can trigger both action prediction and interpretation (see, e.g., Bach, Nicholson, & Hudson, 2014).

Our argument is reinforced also by studies conducted within the representational momentum (RM) paradigm (see, e.g., Freyed & Finke, 1984), that differently from the literature on action observation emphasizes a main role of top-down rather than bottom-up processes in predicting an action’s future course. Typically, the participants in these studies see a moving object that suddenly disappears. Immediately after, they see the object displaced slightly either in a potential future position (forward in time) or in a previous position (backward in time). Experimental results reveal that when participants are asked to identify the last and seen position of the object, they tend to accept forward displacements. Most relevant to our investigation, the participants in the studies by Hudson and colleagues (2016a; 2016b) saw hands reach or withdraw from an object. When the participants, before seeing the movement, heard the actor declare the intention to either take or leave the object, they misperceived the hand’s disappearance point as being further along the action trajectory than it actually was (Hudson, Nicholson, Ellis, & Bach, 2016a). The same results held when the participants themselves generated action expectations on the basis of the nature of the object (e.g., the hand will reach a glass, the hand will withdraw from a broken glass; Hudson, Nicholson, Simpson, Ellis, & Bach, 2016b).

We assume that a kinematic mental simulation can give rise to a false memory which consists of a “logical” and temporal continuation of the situation depicted in a photo. Globally considered, the results in the neurocognitive and the RM literatures enforce the assumption that the state of affairs in which the actor is dynamically performing the action is the necessary consequence of the situation depicted in the original photo, in which the actor was near to perform the action. Mental model theory for false memories resulting from kinematic mental simulation explains false memories arising from the observation of frames of sequences of actions or movies obtained in previous work (e.g., Hannigan & Reinitz, 2001) as due to the kinematic mental simulation induced by the sequences of frames or movies. With the exception of the studies conducted within the representational momentum paradigm, all previous studies employing visual material detected false memories resulting from *backward* inferences, namely inferring a cause (i.e., a person hitting the oranges, or the actions leading to the final LEGO vehicle) from an observed effect (e.g., oranges on the floor, or a built LEGO vehicle; Hannigan & Reinitz, 2001, and Foster & Garry 2012, respectively). In these studies, in addition, the nature of the backward inference was not clear. Inferring the cause from an effect could also be based on logical/verbal backward inferences. Within the framework proposed in the present study, a false memory about an action can arise from a specific mental simulation, i.e. a mental movie rewinding or unfolding in time, and that should then produce both backward and forward inferences, respectively.

Ours is the first attempt to show that false memories *for actions* from purely visual scenes can be obtained for future events (e.g., effects stemming from a cause), and not just for causes or missing middle pieces of actions, as previously shown. Previous work showing false memories for future events used verbal material (Johnson, Bransford, & Solomon, 1973) also accompanied by photos (Henkel, 2012). In our case only visual material (still frames of actions) is presented. From our viewpoint, also the studies conducted on action observation (e.g., Hudson et al., 2016a) induced a kinematic mental simulation by declaring or by having participants declare the goal of the actor before the action is observed. Also, since the construction of a kinematic mental model corresponds to a deep processing of the information in the scenario, we predicted that its product, namely a false memory, can still occur after days. The focus on memory for single static situations, using exclusively visual material, testing an effect on false memories detectable after a time interval of days rather than seconds, assessing the possibility that these false memories occur for future states (e.g., consequences) and not past states (e.g., causes), are the main elements of novelty of our investigation.

An Investigation on False Memories from Kinematic Mental Simulation

In our experiments the participants saw a series of photos in which an actor is *near to perform an action on an object* (for example, *is reaching for a bottle*). In both Experiments 1 and 2, three days later they performed a recognition task in which they encountered, along with all original photos, three new photos depicting the same actor and the same object (see Figure 1). We explain in some detail the material as this is necessary to describe the experiments. One of the three photos represents a situation that should be part of the mental simulation of the original action (in the example above, the actor *while performing the action, i.e., drinking from the bottle)*, and thus could result from a kinematic mental simulation from the photo (for this reason we shall refer to such photo – and action as 'forward'. For example, in Figure 1, if the presented photo is A1, the 'forward' photo is A2). The other two photos depict the same actor near to perform and while performing a different action on the same object, exactly in the same environment (e.g., picking up the bottle to pour the water; pouring the water in a glass). We shall refer to these photos as 'other1' (B1 in Figure 1) and 'other2' (B2 in Figure 1), respectively. To be noticed that the situation depicted in 'other2' should also be part of a mental scenario, but this time should be part of the mental scenario created on the basis of the action depicted in 'other1'. Thus it should correspond to the situation/action resulting from the kinematic mental simulation stemming from 'other1'. The pairs 'original'-'forward', and 'other1'-'other2' pertain each to a specific kinematic pattern that features the motion of an agent with a specific intention. Thus, presenting 'original' or 'other1' results in two different simulations and therefore in two different inferences: specifically, ‘forward’ and ‘other2’, respectively.

Insert Figure 1 about here

For the way they were created, these photos should differ in perceptual similarity. For example, assuming that in Figure 1 the ‘original’ is A1, the photo in which the actor is near to pour from the bottle (photo B1 in Figure 1, in general ‘other1’) is the most similar to the original photo of holding the bottle to drink (A1), and because of the high level of perceptual similarity should be the most likely false recognition. The photo depicting the actor while accomplishing the action different from the original one (B2 in Figure 1, in general ‘other2’) should be the most dissimilar from the original and thus the least likely to be falsely recognized. The critical photo, and the most interesting for our prediction, is the ‘forward’ one (A2 in Figure 1) depicting the actor while performing the action that the actor was near to perform in the original photo (A1). As B2’, this photo is also perceptually different from the original, and based on perceptual similarity also unlikely to be falsely recognized. However, we predict that it will be falsely recognized because it is part of the kinematic mental simulation that stems from the original photo (A1).

Within our proposed theoretical framework, kinematic false memories (‘forward’) and other kinds of memory (‘original’, ‘other1’ and ‘other2’) rely on different cognitive mechanisms: the former rely on a mental simulation and the latter on perceptual processes. From these assumptions descend three main predictions.

The first prediction, tested in both Experiment 1 and Experiment 2, concerns a trend in acceptance ratings for ‘original’ photo and distractors. In particular, if recognition relies only on perceptual processes, then ‘other1’ photo should be misrecognized more often than ‘forward’ photo, which in turn should be misrecognized more often than ‘other2’ photo. If instead the participants rely also on kinematic mental simulations, then ‘forward’ photo should be misrecognize to the same extent as ‘other1’ photo, and more than ‘other2’ photo.

The second prediction, also tested in both Experiments 1 and 2, is that ‘forward’ photo is more likely than ‘other1’ photo to be rated with extreme ratings on a five-point Likert scale (i.e., 1 = ‘I certainly didn’t see the photo’; 5 = ‘I certainly saw the photo’), and ‘other1’ photo is more likely than ‘forward’ photo to be rated with uncertainty (i.e., 2, 3, or 4). The rationale is the following. Given that ‘forward’ photo represents the exact result of the kinematic mental simulation triggered by the ‘original’ photo, we predict that when the participants’ response relies on this simulation, the recognition of ‘forward’ photo should be certain (i.e., 5). Otherwise, if they do not use mental simulations, confidence in recognition should be at floor level (i.e., 1). Instead, ‘other 1’ photo is very similar to the ‘original’ photo but at the same time it doesn’t fully fit with it. Then recognition of ‘other1’ should always be rather uncertain (i.e., 2, 3, 4). To sum up, ‘other1’ photo is more likely than ‘forward’ photo to be rated with uncertainty (i.e., 2, 3, or 4) and ‘forward’ photo is more likely than ‘other1’ photo to be rated with certainty (i.e., 1 or 5).

The third prediction is tested in Experiment 2 and concerns the ineffectiveness of information on the nature of the stimuli received by participants. The main assumption underlying our investigation is that the observation of an actor *near to perform* an action elicits in the observer a kinematic simulation in which the action unfolds in time and represents the agent *while performing* that action. To make a kinematic mental simulation is to imagine a step-by-step developing action that maintains vivid perceptual elements (static and kinematic) of the original. Studies revealed that at least in some circumstances, imagery recruits the same mechanisms used in the early phases of perceptual processing (Kosslyn, Thompson, & Ganis, 2006). As a consequence, imagery makes explicit and accessible the same types of information that are registered by the senses during perception (Moulton & Kosslyn, 2009). This should hold also for kinematic mental simulations. Therefore from our assumption and from evidence in the literature, we derive the prediction that the kinematic mental simulation is sufficiently vivid and percept-like to trick the monitoring system (Johnson, Hastroudy & Lindsay, 1973) even when instructions given at recognition make explicit the nature of the material used (i.e. participants are informed that the recognition material comprises pairs of photos, not all presented, each pair selected as portraying two steps of an unfolding action on the same object). In other words, we should observe no specific reduction in false memories deriving from kinematic mental simulations because of the vividness of the perceptual static and kinematic details of the mental simulation which are similar to those involved in recalling true memories.

We ran a first study, preliminary to the experiments proper, aimed at confirming the levels of perceptual similarities between the original photo and the other photos. The investigation was approved by the Bioethical Committee of Hull University and by the Bioethical Committee of Turin University.

Preliminary study. Perceptual similarity of the stimuli

The aim of the study was to assess the perceptual similarity of experimental stimuli that were then to be used in Experiments 1 and 2. Specifically we assessed the level of perceptual similarity between the original photo and the three distractor photos presented for recognition.

Method

Participants. Twenty students from Turin University (6 males and 14 females; mean age = 23.3 years) voluntarily took part in the experiment in exchange of course credits and after informed consent.

Material. For this initial study, as in part already described in the introduction, series of pairs of videos were first created in which the same actor performed two different actions on the same object in the very same environmental setting. For each video, we set the onset of the action at the moment in which the actor starts to move and the end at the moment in which the action is completed. For each video two still frames were extracted. In one the actor is *near to perform* the action (‘original’ photo, see Figure 1; e.g., A1 she is reaching for the bottle). This still frame was taken at 2/3 of the entire video’s length. In the other the actor *is performing* the action (‘forward’ photo, e.g., A2, she is drinking from the bottle; ‘other2’, e.g., B2, in which the actor has completed a different action ‘other1’, e.g., B1). In both videos the actor was instructed to enter the scene in the same way when performing the two actions. The four still frames in which the same object was used were grouped together, resulting in 10 sets of 4 photos each, each set composed of an ‘original’ photo, a ‘forward’ photo, an ‘other1’ photo and an ‘other2’ photo. The Appendix illustrates the 10 quadruplets of photos.

Design and Procedure. Either A1 or B1 of each quadruplet were used as the ‘original’ photo. For half of the participants the ‘original’ photos were A1 photos in the quadruplets from 1 to 5 in the Appendix, and B1 photos in the quadruplets from 6 to 10. For the other half of participants, the ‘original’ photos were B1 in the quadruplets from 1 to 5 in the Appendix, and the photos A1 in the quadruplets from 6 to 10. The experiment was run in a single session.

The participants were invited to imagine themselves in a critical situation: “You are at a friend’s house in front of a fireplace and you are looking at several photographs. At a certain point your friend exits the room and you, inadvertently, drop one of the photographs in the fireplace. You can not in any way recover the original photo now compromised. The only possible solution is to replace it with another one as similar as possible. In the following pages you will observe the original photograph and three possible alternatives. We ask you to assign a score from 1 to 3 to each of the alternatives, assigning 1 to the photo that would be your first choice and 3 to your last choice. In other words you should answer to the following question: “Which picture would you use to replace the original one?”. These instructions were meant to focus the participants on perceptual similarity rather than “psychological similarity”. We suspected that the explicit instruction to assess the similarity of the stimuli could have lead the participants to substitute the forward photo for the “lost” original one because they anticipated that the owner might confuse it with the original one. Because of the equidistance between the three ratings, the ordinal data obtained were used to measure perceptual distance.

Results and discussion

Figure 2 illustrates the ratings of perceptual similarity. A non-parametric analysis of variance detected a statistically significant difference in the ratings given to the 3 kinds of photos (‘forward’, ‘other1’, ‘other2’) ($\chi^2(2) = 31.92$, $p < .0001$, Kendall’s $W = .80$). At the post hoc analysis with Wilcoxon tests (the Bonferroni correction resulted in a significance level set at $p < .017$), the participants judged the ‘other1’ photos as perceptually more similar to the ‘original’ than ‘forward’ photos (a mean of 1.40, sd = .22 versus a mean of 1.97, sd = .31, respectively; $z = 3.43$, $p < .001$, Cliff’s $\delta = .88$). Also, the participants judged ‘forward’ photos as more similar to the ‘original’ compared to ‘other2’ photos (a mean of 1.97, sd = .31 and a mean of 2.64, sd = .21, respectively; $z = 3.78$, $p < .0001$, Cliff’s $\delta = .94$) and, obviously, ‘other1’ photos as more similar to the ‘original’ compared to ‘other2’ photos (a mean of 1.40, sd = .22 and a mean of 2.64, sd =.21, respectively; $z = 3.93$, $p < .0001$, Cliff’s $\delta = .1$).

Globally considered, the results of the preliminary study confirm that the 3 distractor photos in the quadruplet differ from the ‘original’ and among themselves in perceptual similarity, and that the ‘forward’ photo is more perceptually dissimilar from the original than the ‘other1’ photo.

Insert Figure 2 about here

Experiment 1: False memories for action in recognition as predicted by kinematic mental simulation

The participants in the experiment were invited to observe the same series of ‘original’ photos used in the preliminary study (A1 or B1 photos). In particular, since our aim was to test the prediction that false memories for future events can stem from kinematic mental simulations (and not to ascertain that people spontaneously create a kinematic simulation of the action), we instructed the participants to understand what was happening in the situation depicted in each photo they observed. Participants’ memory for the photos was tested in a recognition task 3 days later. At recognition the participants were presented, along with the ‘original’, the photos ‘forward’, ‘other1’ and ‘other2’. Based on the results of the preliminary study, we predicted that participants would make false recognitions to ‘other1’ photos because of their perceptual similarity. However, if when seeing a still frame of an ongoing action kinematic mental models are created, then false recognitions would be more likely with ‘forward’ photos compared to ‘other2’ photos. Within a mental model framework, only ‘forward’ photos depict the continuation of the action represented in the ‘original’ photo and the kinematic mental simulation that occurs when being exposed to the still action would make it difficult to clearly identify which part of the action was presented and which part was not. Our experiment is open to falsification of the hypothesis: if the participants do not make a kinematic simulation then only perceptual similarity should predict the likelihood to misrecognize the distractors (misrecognition: ‘other1’> ‘forward’> ‘other2’). Also, based on the assumption that false recognition of ‘other1’ photo is based on perceptual processes and false recognition of ‘forward’ photo is based on a kinematic mental simulation, we predicted that uncertain ratings are more frequent for ‘other1’ compared to ‘forward’ photos, while extreme ratings that indicate certainty are more frequent for ‘forward’ compared to ‘other1’ photos.

Method

Participants. Twenty-six Hull University students (24 females, 2 males; mean age 21.6 years) voluntarily took part in the experiment, after informed consent, in exchange of either 1 hour credit or 8£.

Design and Procedure. The experiment consisted of two phases: in the first phase the participants encountered the same 10 quadruplets of photos as in the preliminary study, and in the second phase, three days later, they had a recognition test. In the observation phase each participant saw 20 photos, of which 10 critical ‘original’ photos depicting actions near to be performed (A1 or B1) and 10 non-critical photos (fillers) depicting a second set of completed actions (A2 and B2 from the filler set). Completed filler actions were presented to prevent participants from realizing that the original photos were always depicting action onsets. Using a block experimental design, the ten critical actions were divided in two blocks, with 5 actions each. Half participants observed ‘original’ photos in the first block and ‘other1’ photos in the second block. Blocks were presented in the opposite order to the other half. Within each block, photos were presented in random order. Participants were instructed as follows: “In this phase we will show you several photos. Your task is to carefully observe each photo and try to understand what is happening in the depicted situation without stating it out loud. Each photo is presented for 5 seconds then a black screen appears, with the sentence “press the space bar when you are ready”. This means that when you have understood what is happening in the situation depicted, you can press the space bar and the procedure moves to the next photo. If you don't press the bar, after 10 seconds the next photo will be automatically presented." We introduced a black screen after each photo, thereby providing enough time to run a complete mental simulation.

In the recognition phase, strictly 3 days after the presentation phase, the participants saw 50 photos. For each critical action they saw the relative quadruplet of photos ('original', 'forward', 'other1' and 'other2') for a total of 40 photos. In addition they saw 5 presented fillers (all A2) and 5 new initial action photos of the other 5 presented fillers (A1 instead of A2). The 50 photos were presented in a random order, with the only constraint being that those belonging to the same quadruplet did not occur on two consecutive trials. Participants were asked to give recognition ratings on a five-point scale ranging from 1 ("I certainly didn't see this photo") to 5 ("I certainly did see this photo"), see Roediger & McDermott (1995) for a similar recognition task.

Results and discussion

At the Shapiro-Wilk test the recognition ratings of the correct photos did significantly differ from the normal distribution (S-W test: df(26), $w = .907$, $p = .023$). Statistical analyses were thus performed using nonparametric statistical tests. A preliminary analysis excluded a gender effect. Females did not differ from males for true memories (mean rating 3.9, sd = 0.5 and mean rating 4.3, sd = 0.9, respectively: Mann-Whitney test: $z = .58$, $p = .56$). Also, females did not differ from males for false memories (mean rating 2.5, sd = 0.6 and mean rating 2.6, sd = 0.6, respectively: Mann-Whitney test: $z = .15$, $p = .89$). The data from females and males were then analyzed together.

Figure 3 illustrates the ratings assigned by the participants in the recognition test. Ratings were statistically different across kinds of photos ($\chi^2(3) = 52.25$, $p < .0001$, Kendall's $W = .67$). As predicted, at the post hoc analysis (Wilcoxon tests -the Bonferroni correction resulted in a significance level set at $p < .008$), the participants judged the 'original' photo (a mean of 3.96, sd = .55) more familiar than each of the other distractors (z value varied from 4.33 to 4.46, p value always < .0001, Cliff's δ always > .89). There was also a significant difference between the recognition ratings given to 'forward' photos (a mean of 2.47, sd = .55) and 'other2' photos (a mean of 1.85, sd = .50; $z = 3.59$, $p < .0001$, Cliff's $\delta = .57$). The same result holds for the comparison between 'other1' (a mean of 2.67, sd = .53) and 'other2' ($z = 4.26$, $p < .0001$, Cliff's $\delta = .73$). However, the difference between 'forward' and 'other1' was not significant ($z = 1.25$, $p = .21$).

Since the null effect between 'forward' and 'other1' was critical to our prediction, we performed a Bayes Factor (BF) analysis (see Rouder, Speckman, Sun, Morey, & Iverson, 2009) in order to determine the ratio of evidence in favor of the null hypothesis and of the alternative hypothesis for our pair-wise comparison of interest. Specifically, we compared the ratings given at 'forward' and 'other1' testing the H_0 (no differences between the two ratings) and the H_1 (greater confidence ratings for 'other1' as follows from our preliminary study) using Bayesian t-test. We obtained a BF_{01} of 1.30 for the difference between these two ratings. This suggests that the data actually provide more support for the null hypothesis, being 1.30 times more likely to occur under the null hypothesis, compared to the alternative hypothesis (see, Jarosz & Wiley, 2014).

Insert Figure 3 about here

Our assumptions that ratings given to 'other1' photos depend mostly on perceptual similarity whereas ratings given to 'forward' photos arise from the mental kinematic simulation imply the prediction that participants should be more likely to give uncertain ratings to 'other1' photo whereas they should be more extreme in rating 'forward' photos. We assessed this prediction by splitting the ratings into extreme (ratings of 1 or 5), and uncertain (ratings of 2,3,4) (see Table 1). The analysis of the two ratings confirmed the predictions: extreme ratings (1, 5) were more often assigned to ‘forward’ photos than to ‘other1’ photos, and uncertain ratings (2, 3, 4) were more often assigned to ‘other1’ photos than to ‘forward’ photos (Wilcoxon test: $z = 2.86$, $p < .004$, Cliff’s $\delta = .31$, for both comparisons).

Insert Table 1 about here

Globally considered, the results of Experiment 1 reveal that participants were most confident they had not seen 'other2' photos compared to ‘forward’ photos, and their confidence in recognition for ‘forward’ photos and ‘other1’ photos was not significantly different, although according to the results of the preliminary study ‘forward’ photo is perceptually more different from the original than ‘other1’ photo. If the participants were guided in their recognition memory task by perceptual similarity only, then they should have misrecognized ‘forward’ photo less than ‘other1’ photo. Hence, while ‘other1’ photo might be misrecognized because of perceptual similarity with the ‘original’ photo, ‘forward’ photo is misrecognized because it depicts a situation consistent with the natural continuation of the action depicted in the ‘original’ photo as a result of the kinematic mental simulation. Our assumption on the different cognitive processes underlying misrecognition of ‘other1’ photo and ‘forward’ photo is further enforced by the results of the analysis of their relative extreme and uncertain ratings. The more frequent extreme ratings for ‘forward’ photo compared to ‘other1’ photo enforces our assumption that performing a kinematic mental simulation during the observation phase makes the observer certain of having seen the ‘forward’ photo (the only one that logically and temporally represents a development of the situation depicted in the ‘original’ photo) whereas having not performed the simulation makes the observer certain having not seen the ‘forward’ photo. The more frequent uncertain ratings for ‘other1’ compared to ‘forward’ photo enforces our assumption that the observer is uncertain of having seen ‘other1’ photo, which is perceptually the most similar to ‘original’ photo.

Experiment 2: Instructions on nature of the stimuli do not reduce forward false memories for actions

The aim of Experiment 2 was to test whether the kinematic mental simulation is sufficiently percept-like to trick the monitoring system (Johnson, Hastroudy & Lindsay, 1973). The assumption is that to make a kinematic mental simulation is a tantamount to imagine a step-by-step developing action that maintains vivid perceptual elements (static and kinematic). Therefore, we predict that the memory effects of such simulation cannot be easily monitored even when participants are warned about the nature of the material used (i.e. when participants are informed that the recognition material comprises pairs of photos, not all presented, each pair selected as portraying two steps of an unfolding action on the same object). In other words, instructions on nature of the stimuli should not lead to a specific reduction in false memories deriving from kinematic mental simulations (forward false memories) because of the vividness of the perceptual static and kinematic details of the mental simulation which are similar to those involved in recalling true memories. In particular, the instructions were meant to stress the nature of each quadruplet of photos: two photos depict the actor at different timings of execution of a certain action, and two photos depict the actor at different timings of execution of a different action.

Thus, we predicted a replication of the results obtained in Experiment 1. First, false recognitions would be more likely with ‘forward’ photos compared to ‘other2’ photos. Second, uncertain ratings would be greater for ‘other1’ compared to ‘forward’ photos and extreme ratings would be greater for ‘forward’ compared to ‘other1’ photos.

Method

Participants. Twenty-six Hull university students (14 females, 12 males; mean age 21.6 years) voluntarily took part in the experiment. All of them received either 1 hour credit or 8£.

Design and Procedure. The design and procedure were the same as in Experiment 1, but the instruction at recognition were different: “Please note that during this second part of the experiment, for each photo that you have seen in the first phase, in addition to the original one, three other photos will be presented as well, and in a random order. Therefore for each scenario (e.g., tying a shoe), you will observe overall 4 photos, which are very similar to each other. Specifically, two of the photos are extracted from a video where an actor performs an action on an object (e.g., tying the shoe), while the other two photos are extracted from another video where the same actor performs a different action on the same object (e.g., taking off the shoe). During the first phase you saw only one of these four photos”.

Results

The Shapiro-Wilk test determined that the recognition ratings did not significantly differ from the normal distribution (S-W test: df(26), *w* varied from .93 to .97, *p* varied from < .06 to < .63). Statistical analyses were thus performed using parametric statistical tests. A preliminary analysis excluded a gender effect on either true memories or false memories. Females did not differ from males for true memories (mean rating 3.9, sd = 0.7 and mean rating 3.7, sd = 0.7, respectively: Mann-Whitney test: *z* = .65, *p* = .52), nor for false memories (mean rating 2.6, sd = 0.6 and mean rating 2.6, sd = 0.5, respectively: Mann-Whitney test: *z* = .258, p = .80). The data from females and males were then analyzed together.

Figure 4 illustrates recognition ratings. A repeated measures ANOVA revealed a significant difference in mean ratings across the different kinds of photos (F(1.96,49.09) = 35.35, *p* = <.0001, η_p^2 = .59). Post hoc tests using the Bonferroni correction revealed that, as predicted, the participants were more confident in their recognition of the 'original' photo (a mean of 3.79, sd = .68) than each of the distractors (*p* value always < .0001, Cohen's *d* always > 1.34). Further, as predicted, ratings given to 'forward' were significantly higher than those to 'other2' photos (a mean of 2.58, sd = .54 and a mean of 2.20, sd = .69, respectively: *p* <.04, Cohen's *d* = .59). Also, as in Experiment 2 there was no significant difference in ratings between 'other1' (a mean of 2.54, sd = .55) and 'forward' (*p* = 1). In this experiment, there was no significant difference between 'other1' and 'other2' (*p* = .07).

As in Experiment 1, we determined the ratio of evidence in favor of the null hypothesis and of the alternative hypotheses for our pair-wise comparisons of interest, namely acceptance ratings of 'other1' compared to 'forward'. We ran a paired *t* test between the two ratings by employing the Bayes Factor approach, and we obtained a BF_{01} of 6.04 for the difference between 'other1' and 'forward'. This suggests that the data actually provide more support for the null hypothesis (no differences between the two ratings), being 6.04 times more likely to occur under the null hypothesis, compared to the alternative hypothesis (greater confidence ratings for 'other1' as follows from our preliminary study).

Insert Figure 4 about here

Furthermore, the results for Experiment 2 revealed that extreme ratings (1, 5) were more often assigned to 'forward' photos than to 'other1' photos and uncertain ratings (2, 3, 4) were more often assigned to 'other1' photos than to 'forward' photos (Wilcoxon test: $z = 2.28$, $p < .03$, Cliff's $\delta = .34$, for both comparisons).

Insert Table 2 about here

This experiment confirms the results of Experiment 1, showing that unseen photos depicting the completion of an action are confidently misrecognized as the original photos portraying actions near to completion. Misrecognitions are not different from those for photos that are perceptually similar to the original. The results also show that these memory errors are not affected by information about the nature of the stimuli and the fact that they had seen only one of the four photos.

General Discussion

We assumed that individuals try to make sense of what they observe in a photograph in which actors handle objects by running a kinematic mental simulation of the situation, namely by constructing a dynamic mental model that unfolds in time in the same temporal order of the sequence of events. From the assumption that individuals perform a kinematic mental simulation from the information observed, we derived the predictions that false memories for the continuation or the conclusion of an action may occur also when participants see a single photo portraying an action's onset. Differently from previous work on false memories from visual material (Foster & Garry, 2012; Hanning & Reinitz, 2001) the memory errors that are predicted concern future rather than past states of affairs.

In Experiment 1 we confirmed these predictions. Participants confidently misrecognized photos that were not presented but that portrayed the potential conclusion of the action that was represented in the photos they saw. Participants saw photos in which a dynamic action on an object was at 2/3 towards conclusion (e.g., holding a bottle to drink from it-original photo), and misrecognized the completed actions (forward photo) as presented. These error rates were not dissimilar to those made for photos that portrayed a very similar action to the original one ('other1'), also taken at 2/3 towards conclusion (e.g., holding a bottle to pour from it). These 'other1' photos were evaluated by participants in a preliminary study as perceptually more similar to the originals than the forward photos. The results of Experiment 1 revealed that the level of perceptual similarity with the original (as detected in the preliminary study) is not the only factor affecting misrecognition. The kinematic mental simulation from the original photo leads to a substantial level of misrecognition of the ‘forward’ photo, and to a level not significantly different than ‘other1’ photos, which are perceptually more similar to the ‘original’ compared to ‘forward’.

In Experiment 2 we assessed whether informing the participants, before the recognition task, about the nature of the ‘original’ photos and the distracters would help the monitoring system reject false memories. Results indicated the ineffectiveness of information on the nature of the stimuli. In line with our assumption that kinematic mental simulation is vivid and percept-like, we observed forward false memories even when instructions given at recognition made explicit the nature of the material used. In sum, the vivid static and dynamic details resulting from the kinematic mental simulation run at encoding trick the monitoring system at retrieval. In relation to the results of Experiment 1, those of Experiment 2 seem to suggest that accuracy decreases overall. It is possible that information provided by the instructions to the participants in Experiment 2, which make explicit the potential confusion due to the nature of the stimuli, resulted in a decrease of the overall level of confidence.

The global results of the two experiments evidence the existence of kinematic false memories from still frames of actions; a skeptic might argue that the participants in our experiments did not accept ‘forward’ photos with similar confidence to ‘original’ photos and that, therefore, we are not entitled to consider memories of this kind as false. However, lower confidence for false memories are not unique to our study. In the literature which inspired our investigation, false memories are characterized by lower confidence than the original items. Confidence ratings in our study were assessed with the same 5-point confidence rating scale adopted by Hannigan and Reinitz (2001), who were among the first authors to investigate false memories from still frames (of sequences of actions). Within the theoretical framework they initiated, false memories were accepted with a mean confidence rating of about 2, which is lower than confidence for true memories (mean confidence rating of about 4). In other words, these authors consider to be false also memories perceived with lower confidence than true memories.

Which mechanisms then might be responsible for creating false memories for actions?

In the thirties of the last century, Bartlett (1932) discovered that the participants in his study remembered the events read in a story quite differently from the way they were described in the story itself, and introduced the notion of schema in order to explain the phenomenon. More recently, studies on recognition memory analyzed the effects of scripts on accepting information that is typical but false. For example, the participants in a study by Garcia-Bajos and Migueles (2003) listened to a brief account of a mugging event and at recognition they misrecognized non-presented high typicality sentences such as “The victim is walking down the street”. Similar results were obtained by Yamada and Itsukushima (2013) with visual material: the participants in their study watched consecutive slides describing a man in a kitchen. At recognition, when they encountered verbal descriptions of the slides, they misrecognized non-presented but schema-consistent actions , such as “Breaking eggs”. The misrecognition of ‘forward’ photos in our experiments cannot be accounted for within a script framework. A script account would predict comparable acceptance ratings for ‘forward’ and ‘other2’ as they belong to the same script. The rationale is that the two actions in each quadruplet of photos involve the same actor interacting with the same object in the same environment, and both actions are plausible in that environment. If responses relied on scripts only, then one would observe comparable acceptance ratings for ‘forward’ and ‘other2’. For example, a context in which a person is seating in front of a bottle of water and is reaching it, is compatible both with the script “drinking from a bottle” and “pouring from a bottle”. Instead, we predict a specific role of the mental kinematic simulation, which is a model that unfolds in time a very specific action, and represents the sequence of situations that corresponds to the temporal order of events in the world, real or imaginary (Johnson-Laird, 1983; Schaeken et al., 1996). Several studies suggest that the kinematic features of a specific action are predictive of its end and goal (see, Castiello, 2005). Consistently with this, studies also revealed that the kinematics of a single action depends on the actor's intention: different intentions result in different kinematic patterns (e.g., Sartori, Becchio, Bara, & Castiello, 2009). Hence, the ‘forward’ photo is the necessary consequence of the situation depicted in the ‘original’ photo..

Prior studies in the literature with findings similar to ours outlined how false recognition can occur as a result of inferences that lead to source monitoring errors. Our proposal is consistent with a source monitoring interpretation (see, e.g., Johnson, Hashtroudi, & Lindsay, 1993). Whereas classical false memories can be attributed to a confusion of the image perceived with an image internally generated, kinematic false memories can be attributed to a confusion of the image perceived with the image resulting from a kinematic simulation of the image perceived. Our results enrich the source monitoring framework with a broader definition of mental representations that include both static and kinematic mental imagery.

As far as we know, false memories for future events have been formerly investigated only from verbal material (Johnson, Bransford, & Solomon, 1973) and for verbal material accompanied by photos (Henkel, 2012). We explored forward false memories for actions portrayed in photos, but our assumptions hold also for a kinematic mental model constructed from verbal material. The participants in the experiment by Johnson et al. (1973) heard short stories of few sentence like, for example, ‘The farmers must be warned of the oncoming flood, the sheriff cried. He mounted as quickly as possible since he knew that it would take quite a while to spread all the news’. This was followed by a recognition test with old sentences identical to those in the stories presented, unrelated sentences involving elements from the original stories but inconsistent with the information conveyed by the stories, and inference sentences, not identical to the presented sentences but potentially true by implication. For the story in the example above, the inference sentence was ‘The sheriff mounted his horse as quickly as possible since he knew that it would take quite a while to spread all the news’. The results of the experiment revealed that the participants misrecognized probable consequences of the action described in the original story. The participants in the studies by Henkel (2012) read short stories designed to induce inferences about their conclusions. For example, they read “Sabrina dropped the delicate vase”, that leads to infer that the vase broke. Each story was accompanied by a photo depicting either the likely conclusion (the broken vase), a detail of the story but not the conclusion (the vase before it was dropped), or no photo. A main result of the study was that seeing photos consistent with the inferred conclusions led the participants to falsely claim having read those conclusions. Within our terminology, the participants in these studies run a kinematic mental simulation of the information in each story (i.e., description of a dynamic action), thus inferring a conclusion about the consequence of the action, that later on they misrecognize as the original information. Henkel (2012) used in her experiments both verbal and visual material. However, differently from what we did in our experiments, the visual information in Henkel’s experiments were provided not as a trigger for the mental simulation, but as a way to enforce the inferences drawn by discourse. Differently from her work, we elicited in our participants a forward simulation by inviting them to try to understand what was happening in each photo, whereas Henkel (2012) elicited in the participants to her study a forward simulation by presenting at encoding, along with each story, a photo depicting the natural conclusion.

Globally considered, our results suggest that the mental kinematic simulations can easily lead to false memories. While the construction of a mental kinematic simulation has been found so far to be associated to correct performances (see, e.g., Bucciarelli et al., 2016), this is the first demonstration that it can also lead to mistakes. This is similar to memory errors produced by levels of processing procedures. Kronlund and Whittlesea (2005) modified the standard levels-of-processing procedure by presenting items either once or twice in the study phase. Each item was presented with either a semantic, phonemic or graphemic question. The task of the participants in the test phase was to judge the frequency with which each word had occurred in the study phase. The results reveal that deeper processing at encoding resulted in more accurate judgments of twice-presented items, but also caused an illusion of repetition for items presented only once. As in other procedures that create false memories (e.g., Brainerd & Reyna, 2005), our findings indicate that a deep level of processing and understanding of a given material (i.e., understanding what is happening in the photo) can paradoxically produce false memories.

Before drawing strong conclusions, one should also consider limitations of our investigation. A main limitation is not having tested the predictions deriving from the assumption that kinematic mental simulations are run at encoding, and not at retrieval. The role of encoding could be tested by replicating our experiments and adding a measure of response times during encoding. In our experiments presentation time was fixed, 5 seconds for each photo after which a black screen appeared. Participants had to press the space bar only at this point, in order to move to the next photo. During this time we assume they constructed the mental simulation from the photo observed. Using response times we could assess the relationship between time spent before moving to the next photo and likelihood of misrecognizing the ‘forward’ (and ‘other1’) photo as the ‘original’. A positive relationship would indicate that what happens during encoding predicts misrecognition of ‘forward’ but not of ‘other1’. In addition, still with the aim to ascertain whether mental simulations are run at encoding, a meta-cognitive experiment partially similar to our Experiment 2 could compare the performance of the participants in two conditions. In one condition before the encoding phase participants receive instructions to monitor the source, while in the other condition the instructions are given after the encoding phase. If the kinematic mental simulation is run at encoding, then false memories should be significantly less frequent when participants are informed prior to encoding. A further limit of our investigation concerns its generalizability. In the context of forensic research, for example, it is rather unlikely that witnesses are invited to recall what they previously saw in photos. It is more likely that witnesses are invited to recall what a moving agent was doing in a particular situation. For this reason, future research could explore kinematic false memories from videos depicting a moving agent.

The ecological validity of our study can be assessed by comparing our experimental task with what classically happens in eyewitness contexts. While at recall the task is very similar to the typical task of an eyewitness, a major difference is that the participants in our experiments were invited to make sense of what they observed at encoding. Future studies might verify whether kinematic false memories occur when the participants are not instructed to make sense of the photos or the videos they observe, and when encoding is incidental rather than intentional.

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